

NEPTUNE AS A RADIO SOURCE

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Abstract

The recent Neptune flyby by Voyager 2 added a new planet to the known number of magnetized planets producing non-thermal, low frequency radiations. We review the Neptunian radio emission morphology as observed by the Planetary Radio Astronomy Experiment on board Voyager 2 during a few weeks before and after closest approach. We present the characteristics of two observed recurrent components of the Neptunian kilometric radiation (NKR), the ‘smooth’ and the ‘bursty’ emission. We describe the many specific features of the radio spectrum during the very close approach of the planet. Comparison with the other planetary radiations is emphasized, but is made difficult by the very small amount of usable observations.

1 The Voyager 2 encounter with Neptune

Voyager 2 flew by Neptune on August 25, 1989. This planetary encounter added a fifth planet to the hitherto known number of magnetized planets generating non-thermal radio emissions: The Earth, Jupiter, Saturn and Uranus. In spite of the large amount of very good quality data obtained by the Planetary Radio Astronomy (PRA) and the Plasma Wave (PWS) experiments, several facts strongly limit our capability to interpret the observations of the Neptunian radio components (Figure 1): (i) The latitudinal and longitudinal coverage is poor because the observing geometries were nearly similar on the inbound and the outbound passes; (ii) the observing geometry, in the vicinity of the planet (close encounter), was so much different from the distant one (far encounter) that the phenomenologies observed in the two cases are difficult to compare; (iii) the intrinsic planetary magnetic field, needed to understand the emission properties, is not well described by the models deduced from the magnetometer observations [Ness et al., 1989], in particular close to the surface of the planet, where the radio sources lie. Taking into account these difficulties, we briefly review the observations to date and attempt to discuss them.

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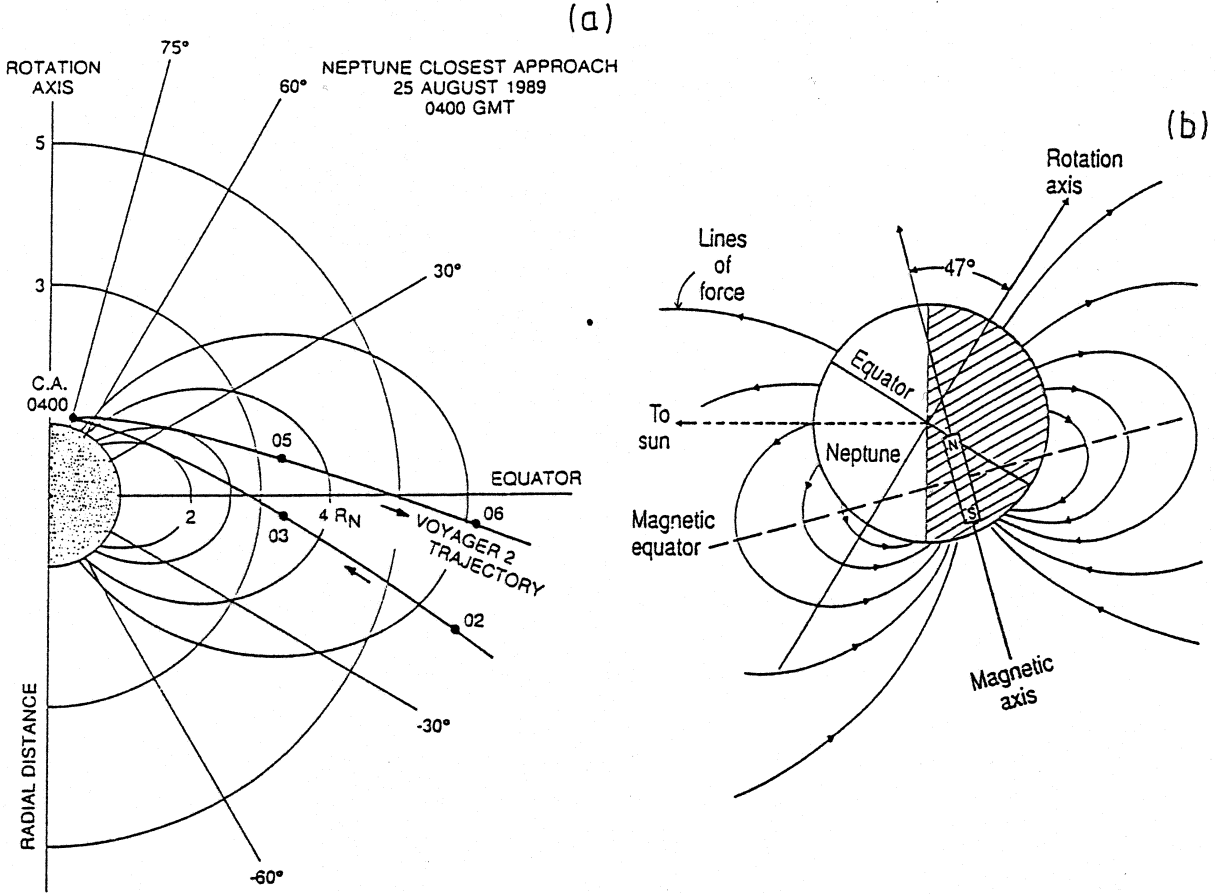


Figure 1: (a) Projection of the Voyager 2 trajectory in the meridian plane containing the spacecraft; (b) diagram of the OTD magnetic field model [Ness et al., 1989] in the meridian plane containing the OTD center and the rotation axis.

2 Observations of the ‘smooth’ (s-NKR) component

Because of its weak intensity, the s-NKR component of Neptunian radio emissions could be observed during only about two weeks around the closest approach. Its average flux density is $0.5 \div 1.0 \times 10^{-22} \text{ Wm}^{-2}\text{Hz}^{-1}$ at the normalized distance of 1 A.U. The peak flux was observed 10 dB higher. Extending, for most of the time, in the 20–600 kHz frequency range, the s-NKR component appears as a quasi-continuous, banded, slowly varying noise of which the intensity and polarization pattern is recurrent from one Neptunian rotation to the other. As illustrated in Figure 4, the s-NKR polarization is mixed, mostly circular in the right-handed sense. The dynamic spectrum may be interpreted as the gradual superposition of two emission patches, in each sense of circular polarization, both drifting in frequency with time but in converse directions. The RH polarization dominates when the observer lies in the northern magnetic hemisphere, consistent with an emission in

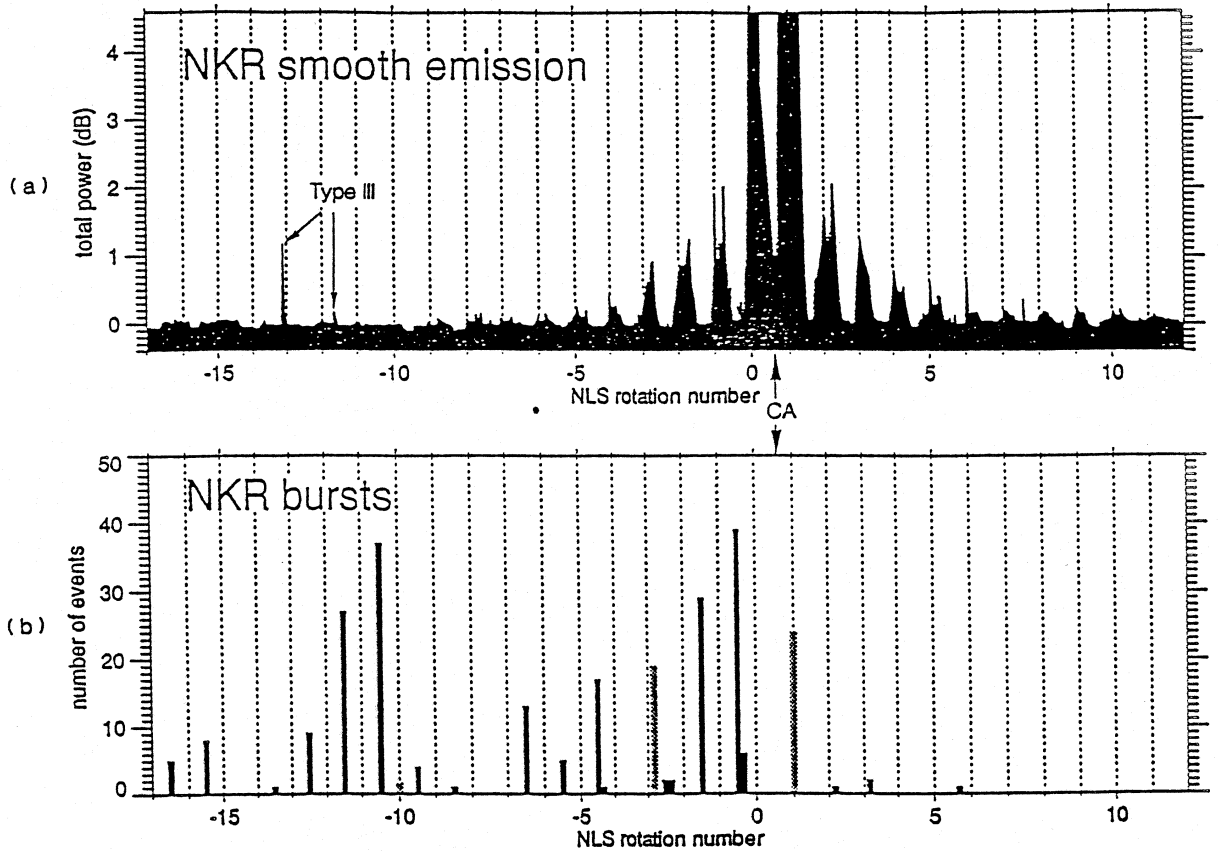


Figure 2: Recurrent occurrence of the two NKR radio components throughout the Neptune encounter as a function of the sub-spacecraft longitude: (a) Integrated intensity of *s*-NKR (frequency range 100–180 kHz) over 16 min, (b) number of *b*-NKR bursts detected within 60° longitude bins.

the extra-ordinary mode. The emission beam likely rotates with the planet: The time-intensity profile displayed a phase change at the closest approach or, equivalently, its phase within the rotational modulation remained the same along the inbound and outbound passes (Figure 2). The maximum intensity was recorded everytime the spacecraft was lying in the Northern hemisphere. The close observations of the dynamic spectrum, during the day around the periapsis (Figure 5), are consistent with the far observations, but with two additional features: During the planetary rotation containing the periapsis, the emission beam was abruptly interrupted between SCET 0330–0400 by one or maybe several occultations of the emitting radiosource(s); on the other hand, a high frequency, detached extension of the dynamic spectrum appeared in the 600–870 kHz frequency range, occurring at nearly the same NLS longitude in both planetary rotations on each side of the closest approach.

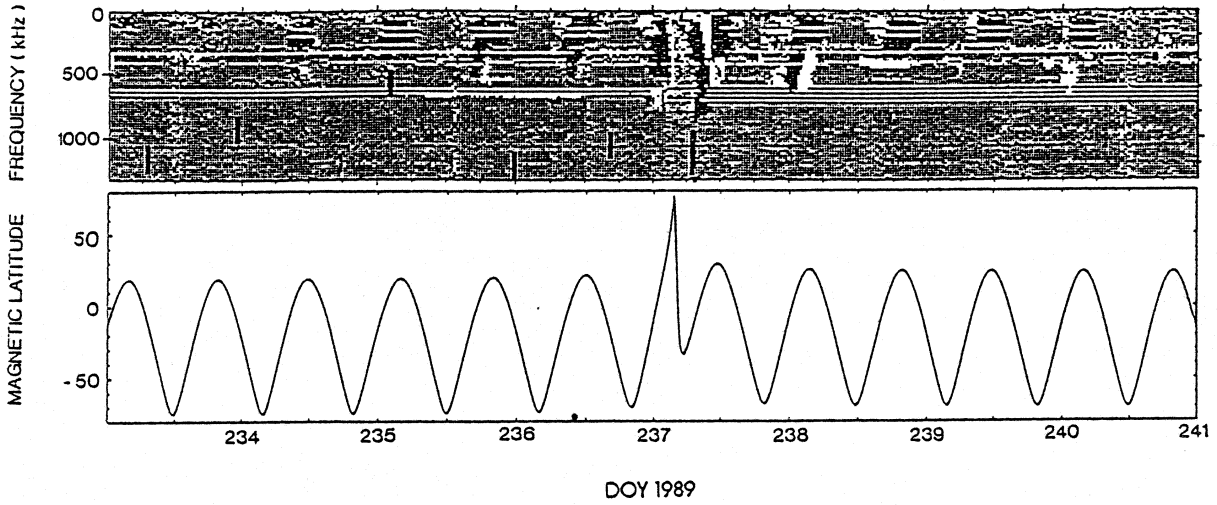


Figure 3: The observed occurrence of s-NKR recorded in the lower frequency range of the PRA experiment (1.2–1326.0 kHz) for ± 4 days around the closest approach of Neptune. Left and right hand circular polarizations are indicated respectively as white and black areas; intermediate gray corresponds to no emission. Horizontal and vertical streaks are interferences. Occurrence of episodes of b-NKR is indicated by black (i.e left-hand polarized) boxes. The lower panel displays the related variations of the magnetic latitude of the spacecraft, computed in the OTD model [Ness et al., 1989].

3 Observations of the ‘bursts’ (b-NKR) component

The larger intensity of the b-NKR component allowed its observation during a period lasting about two months, but essentially along the inbound pass, in the dayside of Neptune. The b-NKR observed activity consists in few tens of short (< 30 msec) and narrow band (< 10 kHz ?) bursts clustered in episodes lasting 30 to 90 minutes and recurrent with the planetary rotation. The frequency range is 420 to 1326 kHz; the last being an instrumental lower limit. The observed polarization is purely LHC (taking into account the unavoidable cross-polarization in the PRA instrument), and changes in RHC at the episode just after the closest approach. The approximate observed flux density, normalized at the 1 A.U. distance, is $10^{-20} \text{ Wm}^{-2}\text{Hz}^{-1}$. Somewhat surprisingly, neither in occurrence (Figure 2) nor in flux (Figure 6), the b-NKR does not show any marked time variation as it should do because of the large distance change between the spacecraft and the source. Nevertheless, the accurate relationship between the b-NKR activity and the rotation of the planet demonstrates its Neptunian origin. The exact nature of this relationship remains unresolved. Not every rotation is active (‘flickering’ source). Two different interpretations of the emission beaming have been given: Warwick et al. [1989] and Boischoit et al. [1992] describe b-NKR as produced by a dayside source with a beam remaining fixed with respect to the Sun’s direction. On the other hand, Desch et al. [1991a] conclude a rotating source which can be seen when the observer lies at low magnetic latitude.

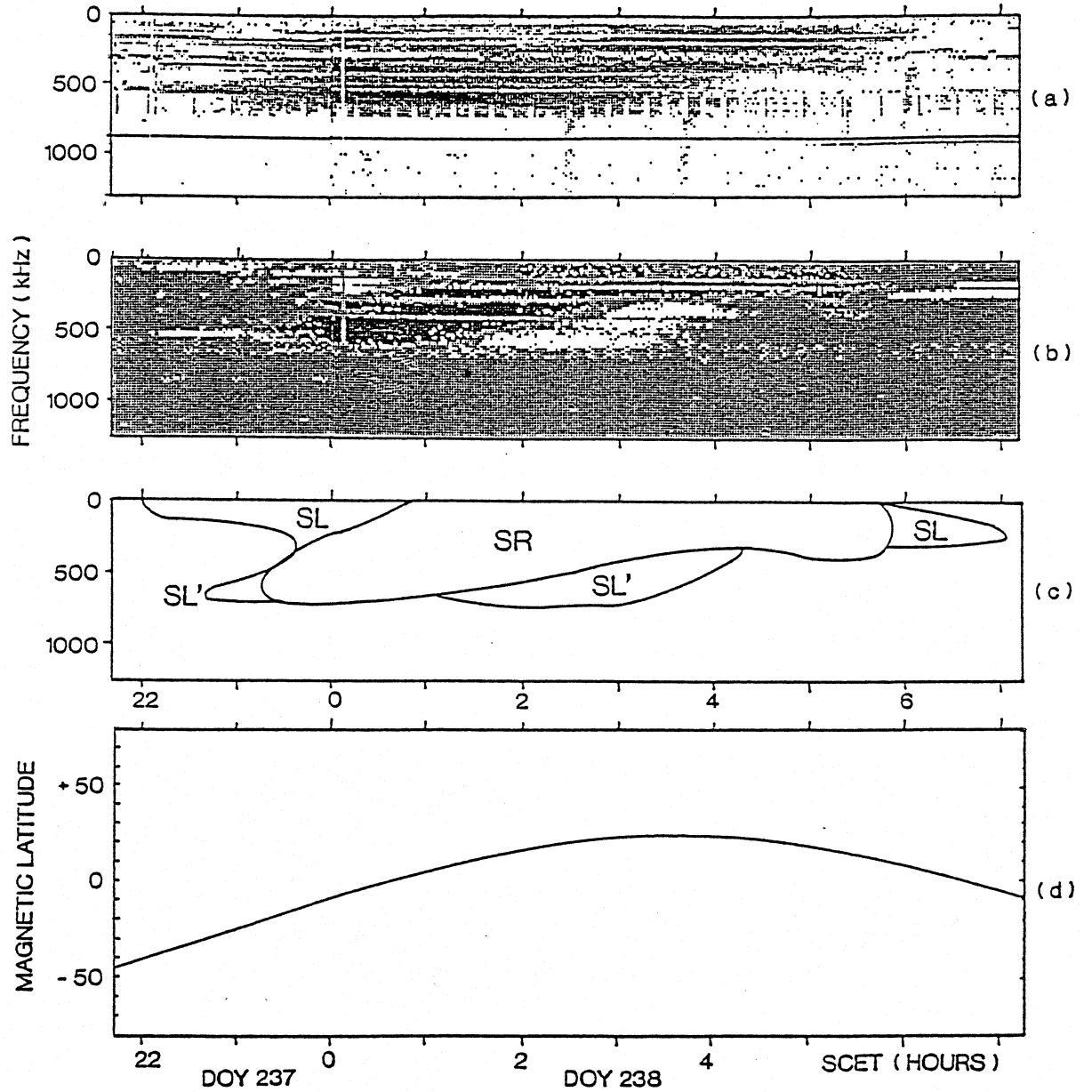


Figure 4: Typical *s*-NKR episode: (a) Total intensity; (b) sense of circular polarization (white=LHC, black=RHC); (c) schematics of the polarization pattern; (d) corresponding OTD magnetic latitude variation.

4 Observations of the non-thermal continuum

The Neptunian counterpart of the VLF non-thermal continuum radiation, already observed in all the planetary magnetospheres (for a comprehensive review, see Kurth [1992]), was observed in the frequency range of 5 to 60 kHz [Gurnett, 1989]. The identification of its cutoff frequency with the electron plasma frequency, leading to an O-mode emission, and the radiation beaming observed within 12° from the magnetic equator, are both in agreement with radiation produced by mode conversion of UHR waves in the equatorial plasma sheet, close to the planet.

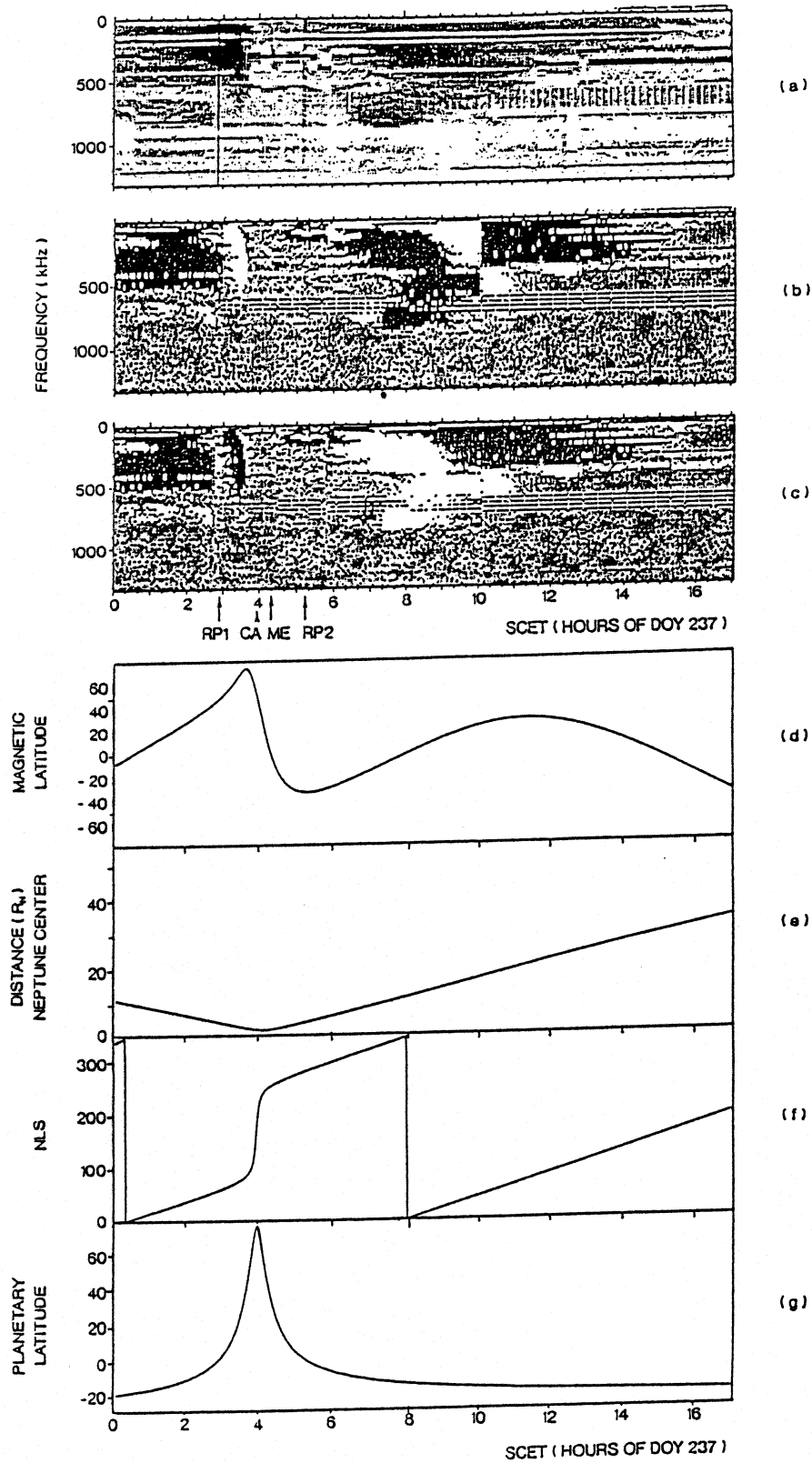


Figure 5: s-NKR PRA observations during the day of the closest approach: (a) Total intensity; (b) apparent polarization (not corrected for antenna response); (c) 'true' polarization, assuming that the observed radiation is coming from the direction of the center of Neptune; (d,e,f,g) various related geometry parameters.

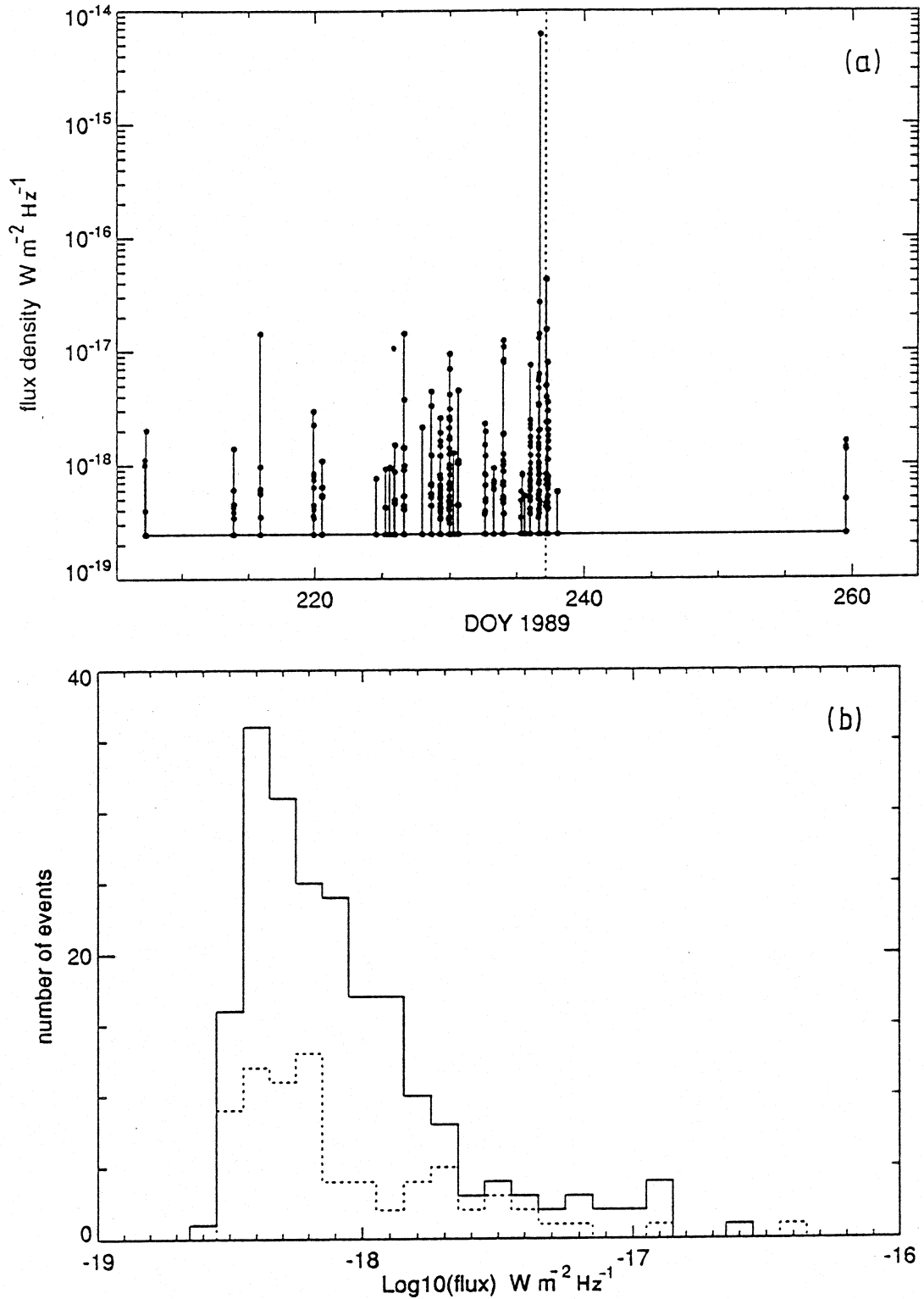


Figure 6: (a) Measured flux densities of individual b-NKR bursts throughout the whole observing period. The observed intensities do not show any significant change with the strongly changing distance to the planet; (b) Distributions of the measured flux densities in each sense of circular polarization (LHC=full line, RHC=dotted line); the RHC distribution is similar to the LHC one but shifted by about 10 dB towards the lowest intensities, suggesting that RHC events are actually LHC events observed in reversed sense by instrumental cross-polarization.

5 Discussion and conclusions

5.1 Origin of s-NKR

Generally speaking, the s-NKR emission resembles the nightside, smooth kilometric radiation observed at Uranus [Desch et al., 1991b] and identified as an auroral emission. But, unlike the Uranian emission, both senses of circular polarization are present. This might be explained by assuming that both magnetic hemispheres are emitting, with conjugate northern and southern sources, as in the case of Earth, Jupiter and Saturn. So, why are the upper frequency limits of the two polarized components nearly equal, since the magnetic field intensities, in the two hemispheres, are so much different? An alternative explanation is that only one hemisphere would be emitting, the observed polarization sense then depending on the view angle. Both hypotheses should be investigated by examining the far encounter observations. While pure circular polarization is the most probable (by analogy with other planets [Ortega and Lecacheux, 1990]), elliptical polarization might be present as suggested [A. Boischot, private communication] by the observed slight differences in onset time during the close encounter occultation event. The UV observations [Broadfoot et al., 1989] lead to auroral zones located at 30° (resp. 200°) NLS and high magnetic latitude in Northern (resp. Southern) hemispheres. A few, tentative radio source locations and models have been published so far [Sawyer et al., 1990; Ladreit et al., 1991]. They conclude in favor of high latitude ($L \approx 6$), Northern and Southern sources, emitting on a substantial part of the auroral ovals. Finally, the origin of the 750 kHz component, clearly detached from the main part of the spectrum and only observed very close to the planet, is still unresolved. It could be a distinct emission component, or a $2f_c$ harmonic emission [P. Zarka, private communication]. A third explanation might arise from the combination of a distorted magnetic field topology and of the observing, changing geometry: This could lead to an extension towards the lower altitudes of the portion of the active field lines observable when the spacecraft lies close to the planet, with an intermediate gap due to a change in curvature of the active field line.

5.2 Origin of b-NKR

The observed properties of the b-NKR component are consistent with an X-mode emission from the Southern hemisphere. The source model is still controversial. Farrell et al. [1990] describe the ‘main’ component as a ‘flickering searchlight’ originating from a source close to the Southern magnetic pole, with a conical beam which is intercepted by the spacecraft twice per rotation. Desch et al. [1991a] add an ‘anomalous’ component, coming from a similar mechanism, but from a slightly different location. This double ‘hot spot’ view of the Southern auroral region might be consistent with the so-called ‘plasma arc model’ [Broadfoot et al., 1989]. On the other hand, Boischot et al. [1992] conclude in favor of a triggered, double source (in phase and out of phase events); in their model, the beam aperture is close to 90° and the triggering feature is located near the South pole. In their study, they emphasize the difficulty of unambiguously identifying the events and question on reliability of some of the ‘anomalous’ bursts found by other authors. Their findings are illustrated in Figure 7: The individual events, as identified by an automatic

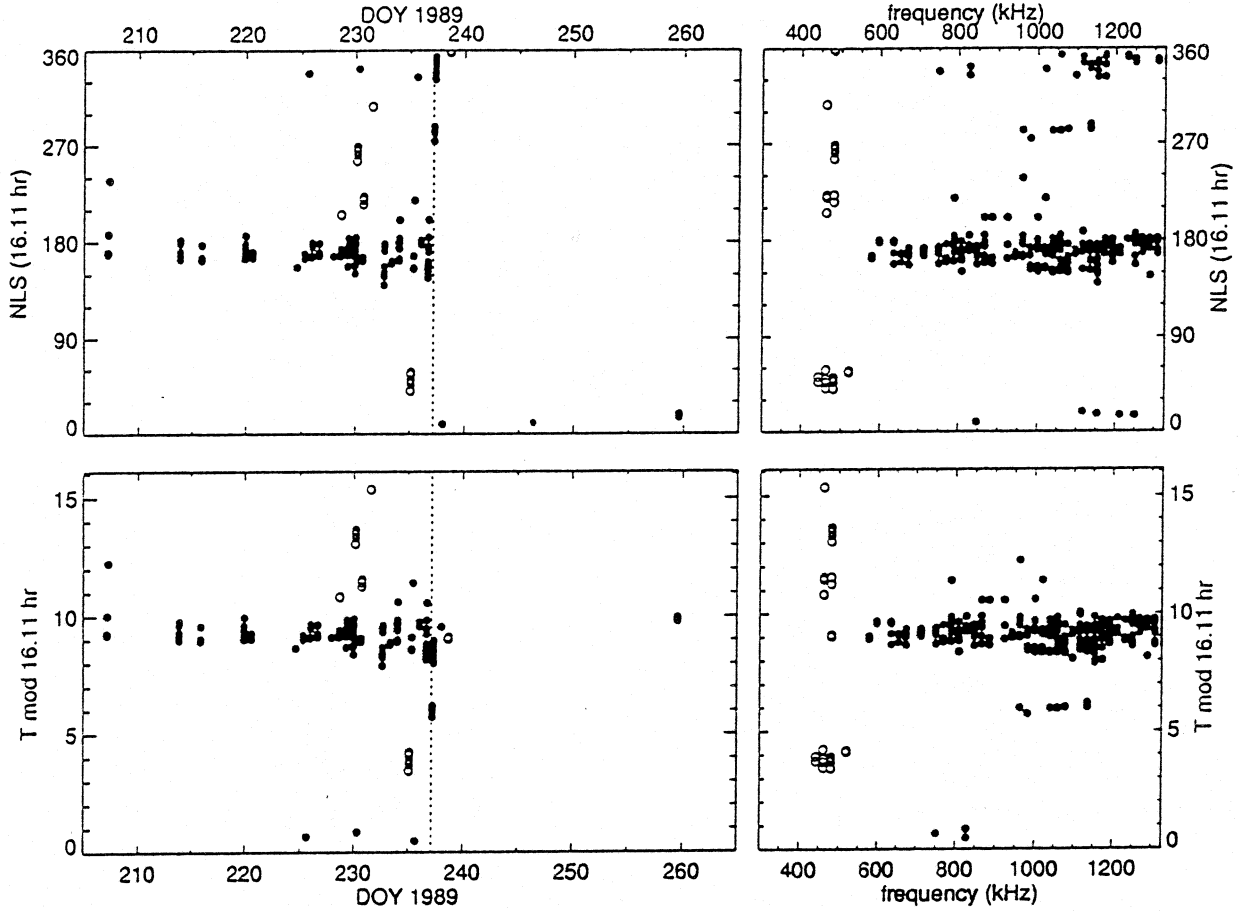


Figure 7: Occurrence of individual b-NKR bursts as a function of the time (left panels) or the frequency (right panels) against sub-spacecraft (upper panels) or sub-solar (lower panels) longitude. Black dots are ‘normal’ events; circles correspond to ‘anomalous’ events [Desch et al., 1991a]. Better organization of the data in the two lower panels is in favor of a beaming geometry fixed with respect to the direction of the Sun.

search algorithm, are plotted in function of time (left panels) or frequency (right panels) against the rotational phase; the two beaming hypotheses are illustrated by each pair of panels (top: beam corotating with the planet, bottom: beam fixed with respect to the Sun to Neptune line). The low frequency ‘anomalous’ events, plotted as empty circles, do not seem to be controlled by the rotation of the planet; on the other hand, they are confined to frequency lower than 500 kHz, suggesting that they might correspond, in fact, to a varying, narrow band interference on the spacecraft. In addition, the ‘beam fixed’ hypothesis (bottom panels) better organizes the data: With the exception of the episode recorded near the closest approach, all the episodes occur in the same range of longitudes, including the late, post-encounter one. This is obviously not the case in the rotating beam model. The b-NKR emission resembles the ‘n-bursty’ component of Uranian kilometric radiation [Desch et al., 1991b]. It was also tentatively compared with the ‘broadband bursty’ radiation at Uranus or with the ‘millisecond’ bursts of Jupiter [Boischot et al., 1992]. This kind of very fast bursts, which are encountered in most of the planetary emissions, might be due to a ‘lasing cyclotron maser’ as originally proposed by Calvert [1982].

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